Evaluating the Stability of a Metric for Determining the Health of Armor Plates

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ABSTRACT

A method for evaluating the stability of a metric for determining the health of armor plates is presented. The metric is based on the following basic premise: The amplitudes and locations of the major vibrational modes of an undamaged armor plate constitute a basic "signature" of the armor plate. Damaging the armor plate should cause changes to both the amplitude and position of the significant vibrational modes. A metric has been developed to exploit these changes in order to distinguish between an undamaged and a damaged plate.

Keywords: *ceramic armor plates, NDT, PZT transducers, damage detection*

INTRODUCTION

Various types of ceramic armor plates are in use by the US military because of their relatively light weight as compared to traditional armor. Obviously, the level of protection is diminished if plate integrity is compromised. Various factors can cause damage to the armor, such as being hit by a projectile in a battlefield situation, or by being damaged in a depot by running into some obstacle. In either situation the vehicle occupants may not be aware that the armor has been compromised. A method has been developed that uses PZT transducers embedded in an armor plate to cause the plate to vibrate at various frequencies. The amplitudes of the vibrations at the various frequencies can be used to generate a characteristic "signature" of the armor plate. A metric has been developed to detect deviations from the signature of a undamaged plate. This paper provides methods for determining the stability of this metric.

GENERAL DESCRIPTION OF THE METHOD

The method starts with a plate that is known to be undamaged. Then the plate is tested by sending waves of various frequencies through the plate and measuring the plate's response. The responses are then stored in a computer and analyzed. If all sources of variability could be removed from the test procedure, the test results would always be identical. However it is impossible to remove all the sources of variability. The only factor that can be assumed to be constant is the following: If exactly the same data is presented to the computer, the output will be identical. By describing the method of gathering the data we can get a better handle on the sources of variability. A sinusoidal wave of a given frequency is sent to one PZT transducer in the armor plate. This signal causes the PZT transducer to vibrate and it induces vibrations throughout the armor plate. A second PZT transducer located at another location in the armor plate receives these vibrations and it causes the transducer to send an electrical signal to the computer. After sufficient data has been collected at a given frequency, a new sinusoidal wave of a different frequency is transmitted. The process continues over a rather wide frequency range. The software that controls the signal generator which generates the sine wave introduces variability in the system both in the signal that it generates and in the time it generates a given frequency. Subtle changes in the ambient conditions including temperature, humidity and vibration may also modify the plate's vibration.

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Report Documentation Page	*Form Approved* *OMB No. 0704-0188*

1. REPORT DATE **04 APR 2011**	2. REPORT TYPE **Journal Article**	3. DATES COVERED **04-04-2011 to 04-04-2011**

4. TITLE AND SUBTITLE **EVALUATING THE STABILITY OF A METRIC FOR DETERMINING THE HEALTH OF ARMOR PLATES**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S) **Thomas Meitzler; Thomas Reynolds; Samuel Ebenstein; Gregory Smith**	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **U.S. Army TARDEC ,6501 E.11 Mile Rd,Warren,MI,48397-5000**	8. PERFORMING ORGANIZATION REPORT NUMBER **#21731**
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) **U.S. Army TARDEC, 6501 E.11 Mile Rd, Warren, MI, 48397-5000**	10. SPONSOR/MONITOR’S ACRONYM(S) **TARDEC** 11. SPONSOR/MONITOR’S REPORT NUMBER(S) **#21731**

12. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

Submitted to Army Science And Technology (ASNT)

14. ABSTRACT

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15. SUBJECT TERMS

ceramic armor plates, NDT, PZT transducers, damage detection

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**8**	

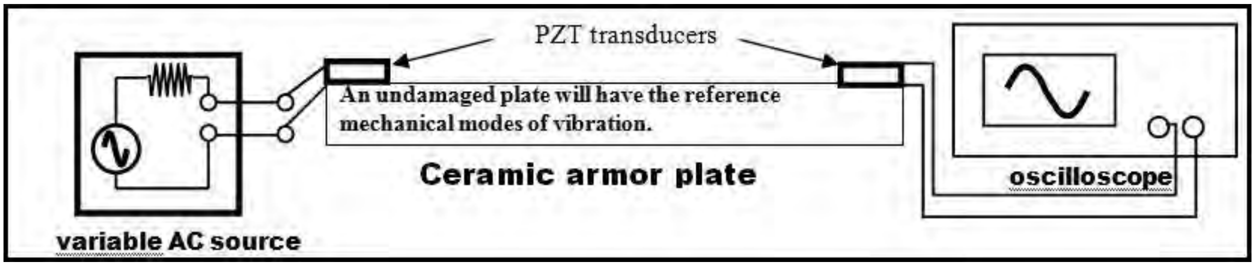

Figure 1: Schematic of the test circuit with a ceramic plate

OBTAINING THE “IDEAL” METRIC VALUE FOR THE ARMOR PLATE

The question is how to obtain the values that represent the plate measured under ideal conditions, “i.e. with no experimental error”. After we obtain these baseline values we can compare measured values to the baseline values. We make the assumption that all experimental errors are randomly distributed in such a way that the mean value of each error is 0. Thus by averaging the variables from several runs we can minimize the error. By collecting more data we can lessen the effect of the experimental error. So for example if we measure 200 variables for each experiment and do 20 experiments, then the ideal value for each variable will be obtained by averaging over the 20 values from each of the experiments for that variable. The data need to be collected under as many different conditions as possible to get a good handle on the spread or deviation that may occur for an undamaged plate. Once we know the envelope of metric values that is developed only from an undamaged plate data, values outside this range indicate a damaged plate. It is important to get as close to the ideal metric as possible from our “healthy data”, since it is much easier to obtain and measure an undamaged plate than a damaged one. There is no problem in measuring a damaged plate, however they are often difficult to obtain.

COLLECTING THE EXPERIMENTAL DATA

Each test of the composite plate consists of running the same experiment 10 times in quick succession. Since each test takes less than 10 seconds, the experiment takes less than 2 minutes after the experimental setup. The experiment was run 31 times over a period of two days for a total of 310 individual runs. See Figure 1 above for a diagram of the basic technique of using piezoelectric transducers for health monitoring described in Meitzler [1,2,3]. Figure 2 below shows a beam of sensor enhanced armor that was used in developing the metric. In Figure 3 we can see the sensor wires that are attached to the embedded PZT sensor. Figure 4 shows a close up view of the damage to the beam. Table 4 below shows the metric values obtained from each run. To prevent bad data from influencing the metric we discard tests which have too large a metric and appear to be “outliers”. They may occur because of some unobserved abnormality in the test conditions, (loose wire, etc). Since the metric values are roughly like normal scores, we exclude tests which have a metric score greater than 2.56, since this should naturally occur less than 1% of the time.

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Figure 2: Beam of sensor enhanced composite material

Figure 3: Side view of the Beam showing the sensor wires

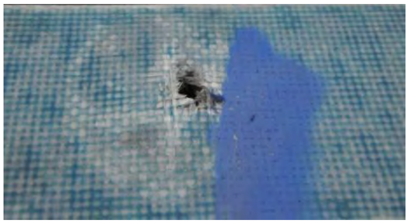

Figure 4: Close up view of the damage to the beam

Test Number	Metric Value
Trial01	1.5675
Trial02	0.3797
Trial03	0.2913
Trial04	1.0028
Trial05	1.1082
Trial06	0.9435
Trial07	0.4525
Trial08	0.4378
Trial09	0.6208
Trial10	1.5519

Table 4: Metric Values Obtained from a run of 10 consecutive tests

As we see from table 4, the values from the trials seem to be quite consistent, and it seems reasonable to test the metric derived from this experiment on our entire set of trials which consists of 310 tests. In all the figures that follow we apply the metric developed from some particular subset of the tests to the entire collection of 310 tests.

This is a reasonable way to get some insight as to whether or not the metric will be useful in distinguishing damaged plates from undamaged ones. It is necessary that the metric return only "healthy values" for every test of the undamaged plate.

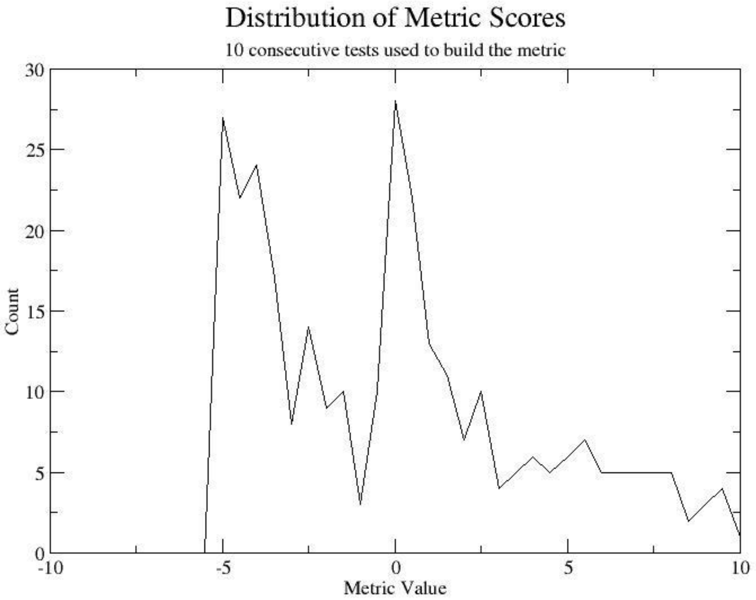

Figure 6: Distribution of metric scores from a metric developed from 10 consecutive tests

In the graph in Figure 5 and the subsequent ones, the average of the data has been subtracted from all the data points so that the metric is centered about 0. This facilitates comparing different graphs. As the graph shows, this metric is not very useful since many good tests have metric values greater than 5 in absolute value, with several larger than 7. This means that we have not captured the natural variability of the process, and we need to do something to reduce the number of outliers and make our graph look more like a normal curve. In order to try to improve our results we decided to use more data. We took the data from 20 consecutive tests and tested it by analyzing all 310 tests as before.

Figure 6 is closer to a normal curve than Figure 5, however there are still too many outliers. We decided on the following process to see how well our metric is working: Select a small subset of the 310 tests using a random number generator. Suppose for example we want to use only 5% of the data and then see how well the metric does on all the data. We evaluate the random number 310 times (one for each file). If the generator value is .05 or less we use the file to develop the metric; if greater than .05 we don't use the file.

Figure 8 shows the results of using this metric. The curve in figure 7 looks much more like a normal curve than any of the previous ones. Although it has been developed from only 5% of the data, there are no values greater than 2.5. It gives us confidence that we have a stable metric which can be used to determine whether or not this armor plate has been damaged.

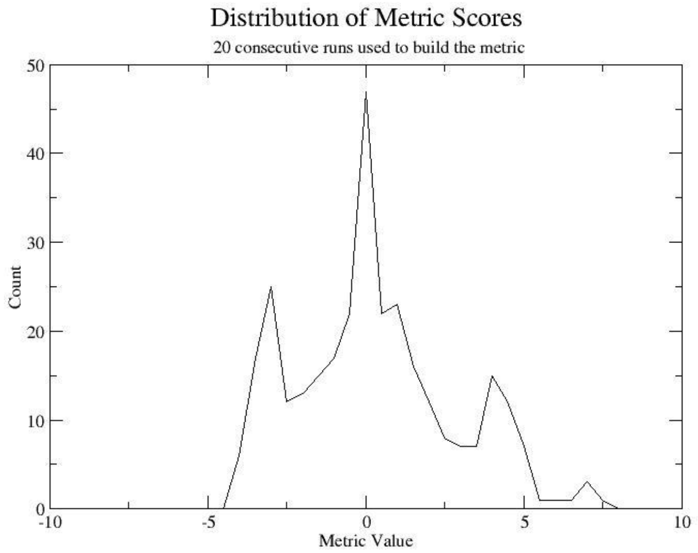

Figure 7: Distribution of metric scores from a metric developed from 20 consecutive tests

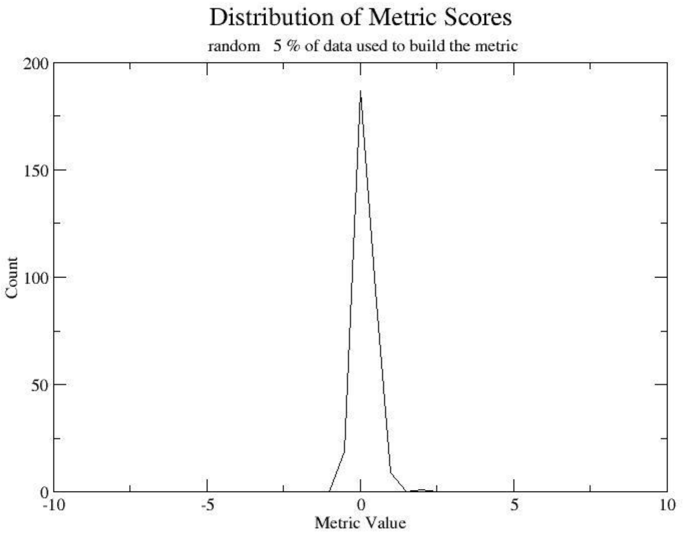

Figure 8: Distribution of metric scores from a metric developed from 5% of the data randomly chosen from the entire data set

The curve in figure 8 looks much more like a normal curve than any of the previous ones. Although it has been developed from only 5% of the data there are no values greater than 2.5. It gives us confidence that we have a stable metric which can be used to determine whether or not this armor plate has been damaged. For the sake of completeness we include the graph where all the data has been used to develop the metric. Figure (9)

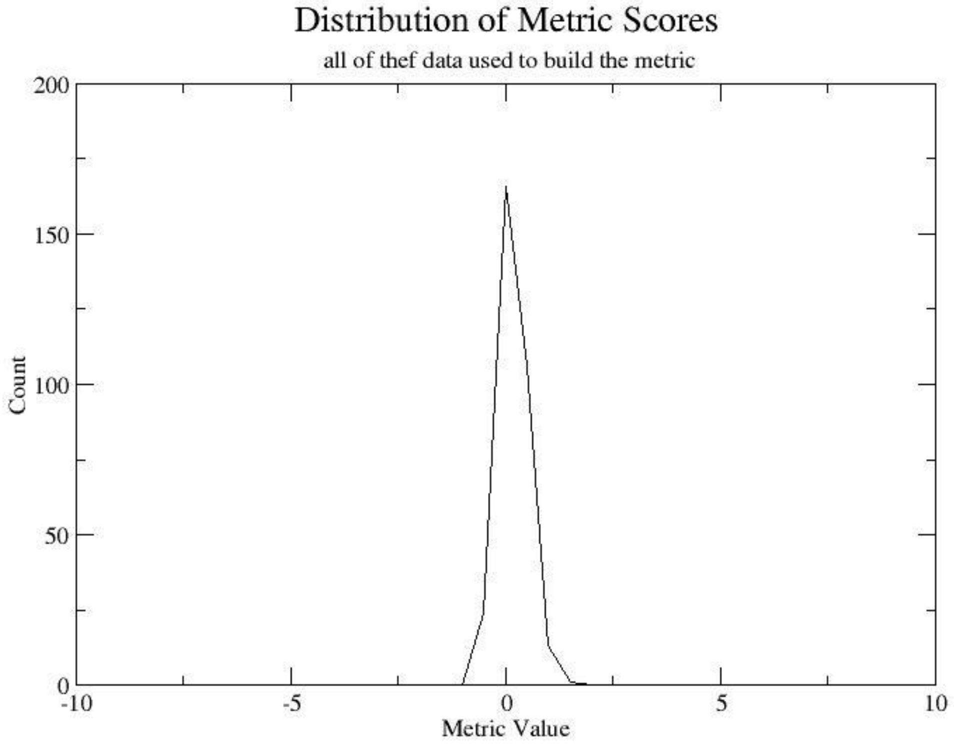

Figure 9: Distribution of metric scores from a metric developed from all the data

At this point we wish to check and see how well the metric is working. We damage the plate with an appropriate projectile and measure it again. The plate was then measured 70 times over a period of approximately 25 minutes. The graph in figure 9 below shows the results. The metric clearly distinguishes between the undamaged plate (values less 3) and the damaged plate (values between 126 and 128).

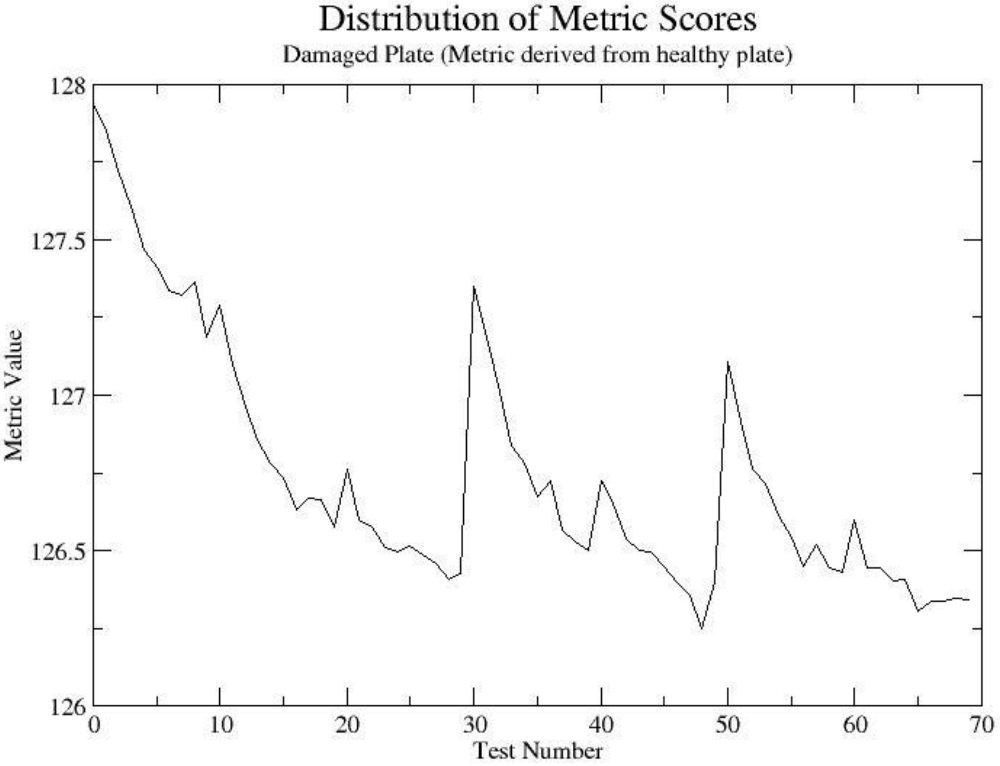

Figure 9: Metric Values Obtained from Measuring a Damaged Plate

CONCLUSION

By testing a healthy armor plate several times under various ambient conditions, a metric can be developed that can be used to differentiate between undamaged and damaged armor plates. The process uses several tests and then randomly picks a small subset of the total tests to develop the metric. The subsequent metric is then tested by comparing the value it gives for the entire set of tests. Visual inspection of the graph of the metric values and their multiplicities can be used to determine the quality of the metric. Finally the plate can be damaged as a final step in verifying that the metric distinguishes between undamaged and damaged plates.

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